RECOMMENDATIONS FOR 15% ABOVE-CODE ENERGY EFFICIENCY MEASURES FOR COMMERCIAL OFFICE BUILDINGS

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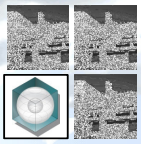

Energy Systems Laboratory
Texas Engineering Experiment Station
Texas A&M University System

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OUTLINE

- Introduction
- Base-Case Building
- Energy Efficiency Measures
- Results
- Conclusion

INTRODUCTION

THE 79TH LEGISLATURE
TO ENHANCE EFFECTIVENESS OF SENATE BILL 5

Requires the Laboratory
To develop 3 methods for achieving at least 15% potential energy savings in residential, commercial and industrial construction.

The Process
Worked on residential and commercial measures
Held stakeholders meetings
Refined measures

BASE-CASE

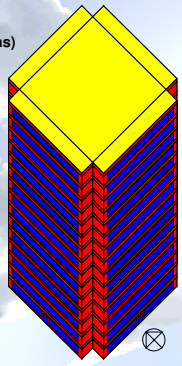
As per ASHRAE 90.1-1999

Two system types:
Electric cooling Natural gas heating (Electric / Gas)
Electric cooling Electric heating (All - Electric)

Building Envelope
- 6-story office building (89,304 ft²) in Houston, TX
- Roof R-value: R-15
- Wall R-value: R-13

Fenestration
- 50% window to wall area ratio
- U-value: 1.22 Btu/hr ºF ft²
- SHGC: 0.44 for North, 0.17 for other orientations

Lighting Power Density
- 1.3 W/ft²



BASE-CASE

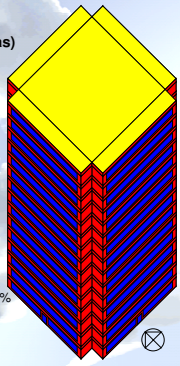
As per ASHRAE 90.1 1999

Two system types:
Electric cooling Natural gas heating (Electric / Gas)
Electric cooling Electric heating (All - Electric)

HVAC System Characteristics
- VAV system with terminal reheat
- Supply air static pressure of 2.5
- Constant supply air temperature of 55F

Plant Characteristics
For cooling
- 160 ton screw chiller with 4.9 COP

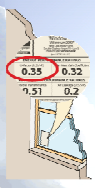
For heating
- Electric/gas building - conventional boiler, 2 - 731 kBtu/hr hot water gas boilers (75% eff)
- All-electric building - electric resistance boiler (100% eff)



ENERGY EFFICIENCY MEASURES

10 INDIVIDUAL MEASURES

Envelope, Fenestration & Space Condition Measures



1. **Decreased Glazing U-value (both)**
   From 1.22 Btu/hr ft² 0.45 Btu/hr ft²

2. **Energy Efficient Lighting**
   Lighting Power Density – From 1.3 W/ ft² to 1 W/ ft²

3. **Window Shading**
   2.5 ft Width of Overhangs on all orientations except north

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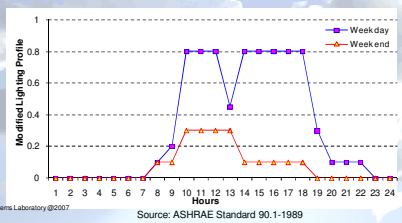
ENERGY EFFICIENCY MEASURES

10 INDIVIDUAL MEASURES

Envelope, Fenestration & Space Condition Measures

4. **Installation of Occupancy Sensors for Lighting**
   Modifying electric lighting profiles



Source: ASHRAE Standard 90.1-1989

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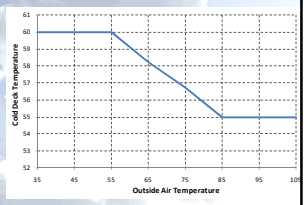
ENERGY EFFICIENCY MEASURES

10 INDIVIDUAL MEASURES

HVAC System Measures

5. **Cold Deck Reset**
   Cold deck temperature decreases linearly as outdoor temperature increases

6. **Supply Fan Total Pressure**
   From 2.5 in.W.G. 1.5 in.W.G.



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ENERGY EFFICIENCY MEASURES

10 INDIVIDUAL MEASURES

Plant Equipment Measures

7. **Chiller COP**
   From 4.9 COP to 6.1 COP

8. **Boiler Efficiency (For Gas Building Only)**
   From 75% to 95% (condensing boiler)

9. **VSD on Chilled Water Pumps**
   From constant speed to variable speed drives

10. **VSD on Hot Water Pumps**
    From constant speed to variable speed drives

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ENERGY EFFICIENCY MEASURES

COMBINED SET OF MEASURES

Combination 1
- Decreased Glazing U-factor
- Decreasing Lighting Power Density

Combination 2
- Occupancy Sensor Installation
- Cold Deck Reset

Combination 3
- Decreased Glazing U-factor
- Raising chiller COP
- VSD on Chilled Water Pump
- VSD on Hot Water Pump

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RESULTS

PROCESS ADOPTED FOR ANALYSIS

CALCULATING ENERGY SAVED
- Annual energy use & demand use for individual and combined measures

CALCULATING COSTS
- Energy Cost
- First Costs

PAYBACK
Number of Years

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RESULTS

Envelope and Fenestration Measures for Electric / Gas Building

EEM	ENERGY USE (MBtu/yr) COOLING	HEATING	DHW	OTHER	TOTAL	ENERGY SAVINGS MBtu/yr	%	$/yr	FIRST COST ($)	PAY BACK ($)
BASECASE	1126	590	43	3899	5658					
GLAZING U-FACTOR	1125	68	43	3815	5051	606	10.7	7,631	95,130 174,150	12-23
LIGHTING LOAD	1064	702	43	3460	5258	389	6.9	18,277	0	0
OCCUPANCY SENSOR	976	879	43	3024	4922	736	13.0	33,032	26,500 28,000	0.8
SHADING	1058	590	43	3859	5549	108	1.9	4,223	67,900 110,000	12-26

Energy Savings
- Glazing – 10.7%
- Lighting Loads - 6.9%
- Occupancy Sensors – 13%

Payback Period
- Lighting Loads - 0 Years

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RESULTS

HVAC System Measures for Electric / Gas Building

EEM	ENERGY USE (Mbtu/yr) COOLING	HEATING	DHW	OTHER	TOTAL	ENERGY SAVINGS Mbtu/yr	%	$/yr	FIRST COST ($)	PAY BACK ($)
BASECASE	1126	590	43	3899	5658					
COLD-DECK RESET	1053	384	43	3905	5385	273	4.8	3,887	0 800	0-0.2
SUPPLY FAN TOTAL PRESSURE	1109	591	43	3841	5583	75	1.3	2,958	0 200	0-0.1

Energy Savings
- Cold Deck Reset – 4.8%

Pay Back Period
- Cold Deck Reset 0 – 0.2 years

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RESULTS

Plant Equipment Measures for Electric / Gas Building

EEM	ENERGY USE (Mbtu/yr) COOLING	HEATING	DHW	OTHER	TOTAL	ENERGY SAVINGS Mbtu/yr	%	$/yr	FIRST COST ($)	PAY BACK ($)
BASECASE	1126	590	43	3899	5658					
CHILLER COP	905	590	43	3899	5436	221	3.9	8,718	16,000 18,000	1.8-2.1
BOILER EFFICIENCY	1126	466	43	3899	5533	124	2.2	993	25,000 35,000	25.2-35.3
VSD ON CHILLED WATER PUMP	1061	590	43	3828	5521	137	2.4	4,885	3,700 4,700	0.8-1.0
VSD ON HOT WATER PUMP	1126	444	43	3868	5481	176	3.1	2,306	4000 5000	1.7-2.2

Energy Savings
- Chiller COP – 3.9%
- VSD on Hot Water Pump – 3.1%

Pay Back Period
- Chiller COP – 1.8 – 2.1 years
- VSD on Hot Water Pump – 1.7 – 2.7 years

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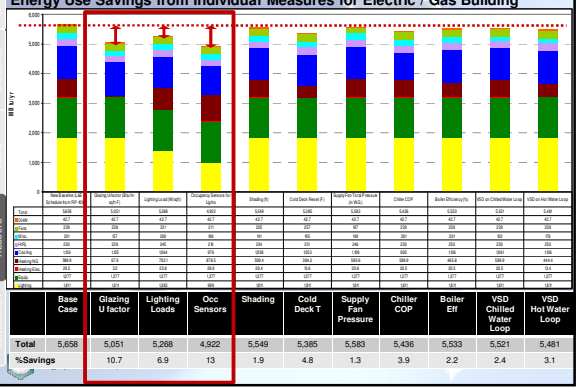
RESULTS

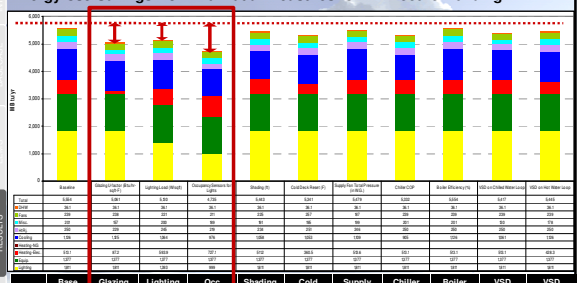
Energy Use Savings from Individual Measures for Electric / Gas Building



	Base Case	Glazing U factor	Lighting Loads	Occ Sensors	Shading	Cold Deck T	Supply Fan Pressure	Chiller COP	Boiler Eff	VSD Chilled Water Loop	VSD Hot Water Loop
Total	5,658	5,051	5,268	4,922	5,549	5,385	5,583	5,436	5,533	5,521	5,481
%Savings		10.7	6.9	13	1.9	4.8	1.3	3.9	2.2	2.4	3.1

RESULTS

Energy Use Savings from Individual Measures for All-Electric Building

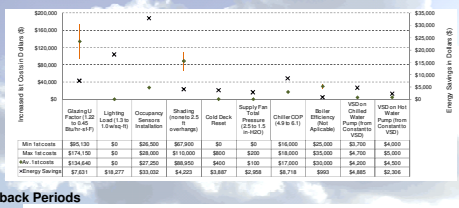


	Base Case	Glazing U factor	Lighting Loads	Occ Sensors	Shading	Cold Deck T	Supply Fan Pressure	Chiller COP	Boiler Eff	VSD Chilled Water Loop	VSD Hot Water Loop
Total	5,554	5,061	5,130	4,735	5,443	5,341	5,479	5,332	5,533	5,417	5,445
%Savings		8.9	7.6	14.7	2.0	3.8	1.4	4.0	0	2.5	2.0

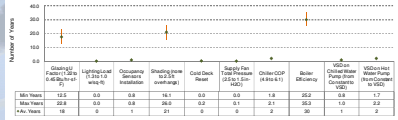
RESULTS

For Electric / Gas Building

Increased First Costs and Energy Savings



Payback Periods



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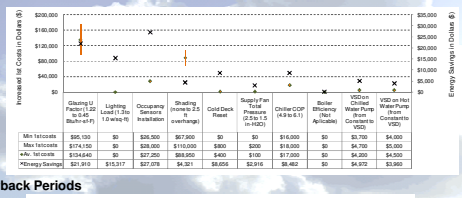
RESULTS

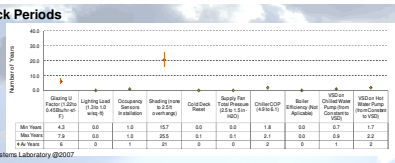
For All - Electric Building

Increased First Costs and Energy Savings



	Glazing U Factor (1.22 to 0.45 Btu/hr-sf-F)	Lighting Load (1.3 to 1.0 w/sq-ft)	Occupancy Sensors Installation	Shading (none to 2.5 overhangs)	Cold Deck Reset	Supply Fan Total Pressure (2.5 to 1.5 in-H2O)	Chiller COP (4.9 to 6.1)	Boiler Efficiency (Non-Applicable)	VSD on Chilled Water Pump (from Constant to VSD)	VSD on Hot Water Pump (from Constant to VSD)
Min 1st costs	$95,130	$0	$26,500	$67,900	$0	$0	$16,000	$0	$3,700	$4,000
Max 1st costs	$174,150	$0	$28,000	$110,000	$800	$200	$18,000	$0	$4,700	$5,000
+Av. 1st costs	$154,640	$0	$27,250	$89,950	$400	$100	$17,000	$0	$4,200	$4,500
*Energy Savings	$21,910	$15,317	$27,078	$4,321	$8,656	$2,916	$8,462	$0	$4,972	$3,960

Payback Periods



	Glazing U Factor (1.22to 0.45Btu/hr-sf-F)	Lighting Load (1.3to 1.0 w/sq-ft)	Occupancy Sensors Installation	Shading (none to 2.5 overhangs)	Cold Deck Reset	Supply Fan Total Pressure (2.5 to 1.5 in-H2O)	Chiller COP (4.9 to 6.1)	Boiler Efficiency (Non-Applicable)	VSD on Chilled Water Pump (from Constant to VSD)	VSD on Hot Water Pump (from Constant to VSD)
Min Years	4.3	0.0	1.0	15.7	0.0	0.0	1.8	0.0	0.7	1.7
Max Years	7.9	0.0	1.0	25.5	0.1	0.1	2.1	0.0	0.9	2.2
+Av Years	6	0	1	21	0	0	2	0	1	2

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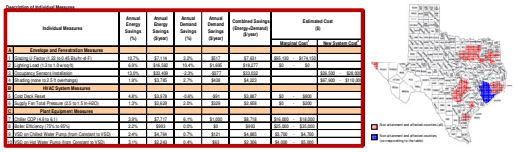
Natural Gas Heating (Brazoria, Fort Bend, Galveston, Harris, Montgomery and Waller Counties)



Individual Measures	Annual Energy Savings (%)	Annual Energy Savings ($/year)	Annual Demand Savings (%)	Annual Demand Savings ($/year)	Combined Savings (Energy+Demand) ($/year)	Estimated Cost ($) Marginal Cost*	Estimated Cost ($) New System Cost*
A Envelope and Fenestration Measures							
1 Glazing U Factor (1.22 to 0.45 Btu/hr-sf-F)	10.7%	$17,149	3.2%	$577	$17,651	$85,130	$174,150
2 Lighting Load (1.3 to 1.0 w/sq-ft)	6.9%	$16,586	19.4%	$1,639	$18,077	$0	$0
3 Occupancy Sensors Installation	1.9%	$25,428	2.3%	$277	$25,633		$26,500 – $28,000
4 Shading (none to 2.5 overhangs)	1.9%	$3,795	2.7%	$439	$4,233		$67,900 – $110,000
B HVAC System Measures							
5 Cold Deck Reset	4.8%	$3,678	0.8%	$91	$3,887	$0	$800
6 Supply Fan Total Pressure (2.5 to 1.5 in-H2O)	1.2%	$2,629	2.2%	$329	$2,958	$0	$200
C Plant Equipment Measures							
7 Chiller COP (4.9 to 6.1)	3.6%	$7,741	6.7%	$1,099	$8,748	$16,000	$18,000
8 Boiler Efficiency (78% to 90%)	2.2%	$992	0.3%	$0	$992	$20,000	$20,000
9 VSD on Chilled Water Pump (from Constant to VSD)	2.4%	$4,794	0.7%	$121	$4,865	$3,700	$4,700
10 VSD on Hot Water Pump (from Constant to VSD)	2.1%	$3,625	0.4%	$83	$3,765	$4,000	$5,000

Description of Combined Measures to Achieve 15% Above Code Savings

Combination of Measures*	Combined Energy Savings (%)	Combined Energy Savings ($/year)	Combined Demand Savings (%)	Combined Demand Savings ($/year)	Combined Savings (Energy+Demand) ($/year)	Combined Estimated Cost ($) Marginal Cost*	Combined Estimated Cost ($) New System Cost*	Combined Annual NOx Emissions Savings (lbs/year)	Combined Ozone Season Period NOx Emissions Savings (lbs/day)	Simple Estimated Payback (yrs)
Combination 1										
1 Glazing U Factor (1.22 to 0.45 Btu/hr-sf-F)	20.1%	$30,743	3.8%	$1,214	$32,273	$85,130	$174,150	256	0.69	3.6 – 6.7
2 Lighting Load (1.3 to 1.0 w/sq-ft)						$0	$0			
Combination 2										
3 Occupancy Sensors Installation	19.6%	$29,856	3.4%	$998	$30,389	$0	$26,500 – $28,000	371	1.37	0.7 – 1.0
4 Cold Deck Reset						$0	$800			
Combination 3										
5 Occupancy Sensors (1.9% to 19.6%)	16.8%	$19,719	9.6%	$1,956	$20,373	$85,130	$174,150	197	0.71	7.5 – 12.4
6 Boiler Efficiency (78% to 90%)						$20,000	$20,000			

Note:
1. Marginal cost = new system cost - original system cost
2. New system cost = new system cost only
3. See individual measures above for specific savings
   * Energy Cost: Electricity cost = $0.119/kWh
   Demand cost = $5.00/kW
   (Yearly demand cost = Sum of monthly demand cost for 12 months
   Natural gas cost = $0.80/therm

(Building Description
- Building type:
- Gross area:
- Building dimension
- Number of floors
- Floor-to-floor height
- Window-to-wall ratio

COMBINATION	COMBINED ENERGY SAVINGS	PAYBACK YEARS
COMBINATION 1	20.1%	3.6 – 6.7
COMBINATION 2	19.6%	0.7
COMBINATION 3	16.8%	7.5 – 12.4

Table 5a: 15% Above Code Savings (Commerc… Heating) for Brazoria, Fort Bend, Galvest… Montgomery and Waller Counties

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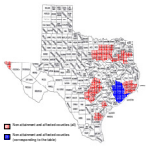
Electric Heating (Brazoria, Fort Bend, Galveston, Harris, Montgomery and Waller Counties)



Individual Measures	Annual Energy Savings (%)	Annual Energy Savings ($/year)	Annual Demand Savings (%)	Annual Demand Savings ($/year)	Combined Savings (Energy+Demand) ($/year)	Estimated Cost ($) Marginal Cost*	Estimated Cost ($) New System Cost*
A Envelope and Fenestration Measures							
1 Glazing U Factor (1.22 to 0.45 Btu/hr-sf-F)	8.9%	$17,594	32.4%	$4,706	$22,300	$85,130	$174,150
2 Lighting Load (1.3 to 1.0 w/sq-ft)	7.6%	$14,774	2.6%	$382	$15,247	$0	$0
3 Occupancy Sensors Installation	14.7%	$29,045	7.9%	$1,463	$27,578		$26,500 – $28,000
4 Shading (none to 2.5 overhangs)	2.2%	$3,849	3.2%	$471	$4,321		$67,900 – $110,000
B HVAC System Measures							
5 Cold Deck Reset	3.8%	$7,412	0.8%	$1,244	$8,656	$0	$800
6 Supply Fan Total Pressure (2.5 to 1.5 in-H2O)	1.4%	$2,916	1.4%	$399	$2,916	$0	$200
C Plant Equipment Measures							
7 Chiller COP (4.9 to 6.1)	4.6%	$7,717	3.1%	$745	$8,462	$16,000	$18,000
8 Boiler Efficiency (Not Aplicable)	n/a	n/a	n/a	n/a	n/a	n/a	n/a
9 VSD on Chilled Water Pump (from Constant to VSD)	2.5%	$4,764	1.5%	$208	$4,972	$3,700	$4,700
10 VSD on Hot Water Pump (from Constant to VSD)	2.0%	$3,757	0.8%	$203	$3,960	$4,000	$5,000

Description of Combined Measures to Achieve 15% Above Code Savings

Combination of Measures*	Combined Energy Savings (%)	Combined Energy Savings ($/year)	Combined Demand Savings (%)	Combined Demand Savings ($/year)	Combined Savings (Energy+Demand) ($/year)	Combined Estimated Cost ($) Marginal Cost*	Combined Estimated Cost ($) New System Cost*	Combined Annual NOx Emissions Savings (lbs/year)	Combined Ozone Season Period NOx Emissions Savings (lbs/day)	Simple Estimated Payback (yrs)
Combination 1										
1 Glazing U Factor (1.22 to 0.45 Btu/hr-sf-F)	19.8%	$36,742	24.8%	$6,237	$42,300	$85,130	$174,150	341	1.38	4.7 – 4.9
2 Lighting Load (1.3 to 1.0 w/sq-ft)						$0	$0			
Combination 2										
3 Occupancy Sensors Installation	19.8%	$36,742	3.5%	$0	$36,742		$26,500 – $28,000	506	1.38	0.7 – 0.8
4 Cold Deck Reset						$0	$800			
Combination 3										
5 Occupancy Sensors (1.9% to 19.8%)	15.9%	$30,098	27.7%	$9,793	$39,899	$85,130	$174,150	297	0.90	6.0 – 6.7
6 Boiler Efficiency (78% to 90%)						$20,000	$20,000			
7 VSD on Hot Water Pump (from Constant to VSD)						$4,000	$5,000			

Note:
1. Marginal cost = new system cost - original system cost
2. New system cost = new system cost only
3. See individual measures above for specific savings
   * Energy Cost: Electricity cost = $0.119/kWh
   Demand cost = $5.00/kW
   (Yearly demand cost = Sum of monthly demand cost for 12 months
   Natural gas cost = $0.80/therm

(Building Descripti
- Building type
- Gross area:
- Building dim
- Number of fl
- Floor-to-floo
- Window-to-w

COMBINATION	COMBINED ENERGY SAVINGS	PAYBACK YEARS
COMBINATION 1	18.5%	2.7 – 4.9
COMBINATION 2	19.8%	0.7
COMBINATION 3	15.5%	4.0 – 6.7

Table 5b: 15% Above Code Savings (Commerc… Heating) for Brazoria, Fort Bend, Galvest… Montgomery and Waller Counties

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CONCLUSIONS

FOR ELECTRIC / GAS BUILDING IN HOUSTON:

Most Effective Individual Measures

	ANNUAL ENERGY SAVINGS	PAYBACK
Glazing U-value	10.7%	18
Lighting Loads	6.9%	0
Occupancy Sensors	1.9%	1

Most Effective Individual Measures

Combination 2

	ANNUAL ENERGY SAVINGS	PAYBACK
Occupancy Sensor Installation	19.6%	0.7
Cold Deck Reset		

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CONCLUSIONS

FOR ALL - ELECTRIC BUILDING IN HOUSTON:

Most Effective Individual Measures

	ANNUAL ENERGY SAVINGS	PAYBACK
Glazing U-value	8.9%	6
Lighting Loads	7.6%	0
Occupancy Sensors	14.7%	1

Most Effective Individual Measures

Combination 2

	ANNUAL ENERGY SAVINGS	PAYBACK
Occupancy Sensor Installation	19.8%	0.7 – 0.8
Cold Deck Reset		

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